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An overview of decision-making in cerebrovascular treatment strategies: Part II - Ruptured aneurysms

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ABSTRACT

Introduction: Decision-making for the treatment of ruptured aneurysms is an intricate process, which involves several factors. There has been a rapid advancement in endovascular, but also in the surgical treating field of ruptured intracranial aneurysms, with a growing body of evidence for either treatment technique.
Research question: As there is a wide variety of treatment possibilities, it can be hard to understand the intricacies which lie behind the decision-making process for a given aneurysm.
Materials and methods: An overview of the most relevant literature in decision-making on ruptured intracranial aneurysms is given.
Results: Different decision-altering factors were identified, which can be divided into information from the general evidence, to influential factors such as the patient's age, initial presenting status, and aneurysmal factors such as size, morphology and aneurysmal location.
Discussion and conclusion: This review provides an evidence-based overview of the most pertinent literature on these different aspects of decision-making in ruptured aneurysm cases and provides some recommendations after each of these segments. As always, all different aspects of the patient and aneurysmal factors should be taken into consideration before coming to a conclusion, as to obtain the best possible result for an individual patient.

1. Introduction

Intracranial aneurysm treatment dates back from 1885, when Horsley performed a bilateral cervical carotid artery occlusion for an internal carotid artery (ICA) aneurysm. Over the years, management of intracranial aneurysms changed substantially with the introduction of clipping and the widespread use of the operating microscope in the 1960's (Lai and O'Neill, 2017; Dandy, 1938). Similarly, in the early 1990's, endovascular treatment with Guglielmi detachable coils was introduced in the treatment of aneurysms (Guglielmi et al., 1991). Over time, adjunctive measures such as balloon- and stent-assisted coiling were implemented, and more recently intravascular- and intrasaccular flow divertors, as well as neck-bridging devices were introduced to aid in treating more complex aneurysms and achieving better aneurysm occlusions (Lee et al., 2022).

This abundance of choice, variability in treatment experience and the large variety of aneurysm presentations, shapes, locations, and sizes, results in therapeutic heterogeneity and large variability in decision making. This was found in a study on ruptured intracranial aneurysms, where there was only a 17.5% agreement between the different specialties regarding their preferred treatment modality (Darsaut et al., 2019a).

Generally, the decision-making process for a suitable treatment modality for a particular aneurysm, comes down deciding on different patient- and aneurysm-related factors:

- **Patient related factors** mainly include information coming from general evidence, the patient's age, as well as the initial clinical presentation status which might affect the decision.
- **Aneurysm-related factors** consist of aneurysm size, morphology (wide-neck aneurysms) and aneurysm location.

In this paper, an overview of the most relevant literature will be

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Abbreviations

ICA	internal carotid artery
mRS	modified Rankin Scale
GOS	Glasgow Outcome Scale
RROC	Raymond-Roy occlusion classification
RCT	Randomized controlled trial
ISAT	international subarachnoid aneurysm trial
BRAT	Barrow ruptured aneurysm trial
SAH	subarachnoid hemorrhage
ET	endovascular therapy
PComm	posterior communicating artery
MCA	middle cerebral artery
WFNS	world federation of neurological surgeons
HH	Hunt and Hess
AComm	anterior communicating artery
WNA	Wide-neck aneurysm
BAC	balloon-assisted coiling
SAC	stent-assisted coiling
FD	flow diverter
WEB	Woven EndoBridge
DAPT	Dual antiplatelet therapy
DACA	distal anterior cerebral artery
PICA	posterior inferior cerebellar artery
OphA	carotid-ophthalmic artery
SR	systematic review
RS	retrospective study
PS	prospective study

provided concerning the different factors which guide decision-making in ruptured saccular aneurysm treatment.

2. Aims and methods

This paper aims to provide an overview of the literature that shapes clinical decision-making in the treatment of saccular aneurysms. By critically evaluating and synthesizing the most relevant research, this review intends to create a framework to guide treatment decisions in clinical practice. The review is structured into two main sections: Part I covers unruptured aneurysms, while Part II focuses on ruptured aneurysms.

To build this framework, studies were selected that have made significant contributions to the understanding of intracranial aneurysm management in a real-world setting. These sources include landmark studies, clinical guidelines, expert consensus reports, and influential trials. The selection was driven by the need to highlight the key evidence that clinicians rely on for decision-making.

It is important to approach recent cohort studies with caution, as many centers currently favor an endovascular-first strategy for treating aneurysms. This shift often results in more complex cases being designated to surgical clipping, inherently increasing the risk of complications in these cases. The goal of this overview is not to provide treatment indications, but rather provide evidence when the decision to treat a given ruptured aneurysm is already taken.

In Part II, we concentrate on the unique challenges presented by ruptured intracranial aneurysms. This section emphasizes the critical factors that must be considered when determining treatment strategies. Through this review, we aim to provide clinicians with clear, evidence-based guidance tailored to the complexities of managing ruptured aneurysms.

3. Outcome parameters

The desired goal of aneurysm treatment comes down to having a safe and effective treatment.

The **safety** of a treatment is often summarized in the **clinical outcome** of the patient. This is measured by the modified Rankin Scale (mRS) or the Glasgow Outcome Scale (GOS). The mRS is often dichotomized into scores 0–2 and 3–6, where the latter delineates death or dependency. Similar divisions exist for the GOS, where a score of 1–3 indicates death or dependency, and 4–5 indicates a good clinical outcome (Gaastra et al., 2022). New **neurological deficits or complications** are often missed in the classic mRS- and GOS-grading systems but can lead to debilitating daily complaints. When specific data on this topic is unavailable, it is frequently summarized in a "**morbidity**" parameter.

Treatment **efficacy** is mostly assessed by preventing **rebleeding**. This is often correlated with the degree of **aneurysm occlusion** achieved by the index treatment. In endovascular cohorts, this is scored on the (modified) Raymond-Roy occlusion classification (RROC), delineating between a complete occlusion (grade 1), residual neck filling (without filling of the aneurysmal sack) as a grade 2, and any filling inside the aneurysm sack as a grade 3 occlusion. Grades 1 and 2 are often combined as an adequate occlusion (Pierot et al., 2020; Darsaut et al., 2023). The occlusion-status after microsurgical clipping is often scored in a similar manner. Even after successful initial treatment, a recanalization or regrowth of the aneurysm is possible, with a new risk of a recurrent bleeding. After significant recanalization (RROC 3) during follow-up, the decision for **retreatment** is taken, but a retreatment comes with new risks for procedural complications (Metayer et al., 2021).

4. Patient-related factors influencing decision-making

4.1. Best available general evidence

The first randomized controlled trial (RCT) comparing coiling and microsurgical clipping for ruptured aneurysms was performed in **Helsinki**, where at 1 year follow-up, no major differences in outcome were noted (Koivisto et al., 2000). The International Subarachnoid Aneurysm Trial (**ISAT**), the largest RCT comparing coiling and clipping to date, included 2143 patients (9559 patients screened) with ruptured aneurysms where both treatment modalities were deemed suitable. The study reported a better clinical outcome after coiling, as shown by an mRS of 0–2 in 76.3% of coiled patients compared to 69.4% for clipping after 1 year (Molyneux et al., 2002). Later iterations of ISAT did show that clipping was associated with better angiographic outcomes (82% vs 66% complete occlusion at one year) and fewer retreatments (3.8% vs 17.4% after 20 months) (Molyneux et al., 2005; Campi et al., 2007). The Barrow Ruptured Aneurysm Trial (**BRAT**), which included 500 patients with a subarachnoid hemorrhage (SAH), showed similar results concerning mRS and retreatment rates (McDougall et al., 2012). After longer follow-up intervals however, the mRS-advantage of coil-embolization was lost in both BRAT and ISAT (Spetzler et al., 2020; Molyneux et al., 2015).

A **Cochrane systematic review** comparing clipping and coiling for ruptured aneurysms from 2018 included 2458 aneurysms across 4 RCT's (ISAT being the largest study) and showed similar results with functional outcomes in favor of coiling and angiographic outcomes in favor of clipping (Lindgren et al., 2018). A more recent systematic review from 2022 with 7391 patients from 28 studies, (including prospective studies), revealed similar outcomes, with lower rebleeding rates for clipped patients (Zhu et al., 2022), an overview is presented in Table 1.

Ever since the publication of ISAT, endovascular therapy (ET) has become the preferred treatment modality for ruptured intracranial

Table 1
Overview of patient- and aneurysm related factors influencing treatment decisions in ruptured aneurysms. Abbreviations: RCT: randomized controlled trial, SR: systematic review, RS: retrospective study, PS: prospective study.

Ruptured aneurysms	Favors endovascular	No significant difference	Favors microsurgical	Most relevant evidence	Type of study
General evidence	mRS	Long term mRS	Occlusion	Molyneux et al., 2002	RCT
			Retreatment	McDougall et al., 2012	RCT
			Rebleeding	Lindgren et al., 2018	SR
Elderly population	mRS for ICA/PComm aneurysms	mRS Barthel index	mRS for ACM aneurysms	Molyneux et al., 2002	RCT
		Mortality Rebleeding/retreatment		McDougall et al., 2012	RCT
				Proust et al., 2018	RCT
				Bekelis et al., 2016	RS
				Dawod et al., 2020	Meta-analysis
Young population	mRS/GOS		mRS	Dawod et al., 2020	SR
				Mitchell et al., 2008	RCT-based
Poor clinical presentation		mRS Complications	Lower mortality	Xia et al., 2017	SR
Small aneurysms		mRS Complications		Li et al., 2017	RS
				Zhao et al., 2019	RS
Large/giant aneurysms	Complications	mRS Mortality	Recanalization	Dengler et al., 2016	SR
				Santoro et al., 2022	RS
WNA		mRS Complications Occlusion	Retreatment	Mascitelli et al., 2019	RCT
				Fiorella et al., 2017	SR
				Mascitelli et al., 2021	PS

aneurysms that are deemed treatable by surgical and endovascular therapy. The reasons for this advantage of coiling are pondered to be due to the "angry brain" encountered during microsurgery, with brain edema and need for increased retraction, causing additional damage to an already fragile brain (Golnari et al., 2020).

Many aneurysms however, do not fit the ISAT-cohort (small anterior circulation aneurysms), and therefore uncertainty regarding treatment of these "non-ISAT" aneurysms remains. Since the publication of ISAT, new endovascular techniques have been introduced, but to this date no randomized evidence exists to compare them to clipping. To study this, ISAT-2 was initiated in 2012, including both non-ISAT aneurysms and novel endovascular methods. An interim-analysis in 2019 however did not show any differences (Darsaut et al., 2019b). A score was devised for the selection of treatment modality for ruptured aneurysms in 2021, based on the Japanese stroke database with 3547 patients. This score has 6 prognostic factors to predict poor mRS-outcome at discharge and in-hospital mortality for both treatment modalities. The model was validated on an external Japanese dataset, but care should be taken not to generalize this model, as it is based on an exclusively Japanese population and advanced anatomical factors are lacking (Yoshiyama et al., 2021).

In conclusion, general clinical evidence shows that, compared to clipping, coiling for ruptured aneurysms results in better clinical outcomes at one year, but worse angiographical results, with a higher rebleeding and retreatment-rate compared to clipping when a clinical equipoise exists. At longer follow-up intervals, the difference in clinical outcome for both treatment modalities disappears.

4.2. Age

As individuals age, vascular changes and the presence of multiple comorbidities as well as general frailty can complicate both endovascular therapy (ET) and surgical clipping of aneurysms. Tortuous blood vessels and atherosclerotic plaques can make endovascular access more challenging and elevate the risk of thromboembolic complications. Similarly, surgical clipping becomes more difficult and riskier when dealing with atherosclerotic aneurysms due to the increased complexity in securing the clip effectively (Willinsky et al., 2003; Hamouda et al., 2024; Yue et al., 2016). The 2012 European Stroke Organization guidelines recommend the use of ET in patients with advanced age, as long-term durability of the treatment is of less importance (Steiner et al., 2013). The newer American Heart Association guidelines from 2023 however, give no preference for either treatment modality in older patients (Hoh et al., 2023).

Evidence for **older patients** remains scarce, with only a few publications available. A French RCT compared ET and clipping in 41 patients >70 years old, but showed no difference in mRS- outcome, as can be expected in this underpowered study (Proust et al., 2018). Subgroup analysis of patients aged ≥65 years old in ISAT failed to show any benefit of ET compared to clipping. The only exception was seen when ET was used for older patients with ICA and posterior communicating artery (PComm) aneurysms and in clipping for middle cerebral artery (MCA) aneurysms. The complication risk and presence of delayed neurological deficits were similar in both groups (Catapano et al., 2021). A subgroup-analysis of the elderly population in the BRAT-cohort also failed to show any difference in functional independence one year after treatment (Catapano et al., 2021). Similarly, a retrospective analysis of 3210 Medicare patients, aged ≥65 years, showed no difference in mortality and readmission rates between both treatment modalities (Bekelis et al., 2016). A systematic review of 13 cohort studies including 7137 patients that compared ET and clipping in an older patient cohort (>54 years old) showed no difference between ET and clipping with regards to functional outcome (63% vs 64%) and treatment efficacy (rebleeding and re-treatment) (Dawod et al., 2020).

Younger patients could potentially benefit more from a surgical approach, considering the lower retreatment-rates and smaller risk of rebleeding after microsurgery (Mitchell et al., 2008), but data from the aforementioned systematic review showed better functional outcomes for the ET-group in younger patients (77% vs 69% good neurological outcome) (Dawod et al., 2020). A post-hoc study on the ISAT-data found that there was no difference in mortality for patients aged <40 years who had ET or clipping, and that for these patients a theoretical advantage for clipping exists due to the better long-term protection from SAH (Mitchell et al., 2008).

Decision-making for both elderly and young patients remains difficult, as there are no pre- specified age-groups or clear cut-off values for age-related outcomes. Most evidence on this matter comes either from small studies, or from subgroup analyses, rendering any conclusions difficult.

4.3. Clinical presentation

The clinical severity of a SAH is classified with the World Federation of Neurological Surgeons (WFNS) or Hunt and Hess (HH) grades at presentation, where a higher grade is indicative of a worse prognosis. A WFNS- or HH-grade of 4–5 is regarded as a **poor-grade SAH**, and this accounts for 20–30% of patients. Half of the patients with a poor-grade SAH will have a poor mRS-outcome (Zhao et al., 2016). A systematic review with 3 RCT's and 16 cohort studies included 1416 patients with a

poor-grade SAH. This review did not show any difference in good outcome (34.3% vs 43.5%) or rebleeding (13.6% vs 10.2%) between coiling and clipping, but the coiled group did have a higher mortality rate (34.2% vs 21.5%) (Xia et al., 2017). In these poor-grade SAH patients, factors such as clinical herniation signs and presence of a space-occupying hematoma, as well as age, will also affect clinical outcome, apart from the initial presentation (Schuss et al., 2016; Liu et al., 2020).

There is currently insufficient evidence to decide on the preferred treatment modality based on the initial clinical status alone, and other factors should be included in the decision-making process for poor-grade SAH patients.

5. Aneurysm-related factors

5.1. Size

Small aneurysms (≤3 mm) are challenging for both ET and clipping (endovascular navigation, coil prolapse, insufficient tissue for clip placement, …). There are only two studies which compared ET and clipping for small aneurysms. One study entails a variety of aneurysms, and the other is a cohort of small anterior communicating artery aneurysms (AComm). They both reported no differences in functional outcome (84.9% vs 80% good mRS-outcome) or complication rates (Li et al., 2017; Zhao et al., 2019).

Given the paucity of data on this subject, no conclusions can be made on the best treatment of ruptured small aneurysms.

Large and giant aneurysms (>10 mm and >25 mm respectively) pose different challenges compared to the smaller aneurysms. They often require adjunct endovascular therapies such as stenting or flow diversion to provide a stable scaffold for subsequent coiling and require more complex clip reconstructions and/or bypass surgery.

CLARITY was a prospective study on complications of ET (mainly coiling) in ruptured aneurysms with 782 patients, which showed significantly more thrombo-embolic events when the aneurysm dome was >10 mm (Pierot et al., 2010). A different study by Zhang et al., found that aneurysms >10 mm also had an increased risk of recanalization after ET (Zhang et al., 2018). The **giant intracranial aneurysm study group** published results from prospective and retrospective cohorts with 581 giant aneurysms, where no differences in mortality between clipping and ET were seen (Dengler et al., 2016). An Italian retrospective study with 162 patients also found no differences in mortality or functional outcomes between clipping and ET, but did show more complications and less recanalization in the surgical group (Santoro et al., 2022).

Large and giant aneurysms are a separate entity and remain difficult to treat for both ET and clipping, other factor such as aneurysm morphology and location, as well as calcification-status will play an important role in the selection of the preferred treatment modality.

5.2. Wide-neck aneurysms

Aneurysms with a neck-width of ≥4 mm or a dome-neck ratio <2 are classified as wide-neck aneurysms (WNA). Wide-neck aneurysms often require more complex clip reconstructions and endovascular adjuncts such as stents or flow-diverters to prevent coil protrusion in the parent vessel (Hendricks et al., 2020).

In BRAT, functional outcomes were similar after ET versus clipping in WNA, with poor outcomes in 35% of patients. Microsurgical clipping did display better angiographic outcomes (84% vs 51% complete occlusion) and lower retreatment rates (0% vs 26%) compared to ET. However, these results should be interpreted with caution, as advanced endovascular methods were not widely used yet during BRAT (Mascitelli et al., 2019; Fiorella et al., 2017).

A systematic review on WNA revealed occlusion-rates of 52.5% and 39.8% for clipping and ET respectively, and safety events at one year follow-up were noted in 24.3% and 21.1% (Hendricks et al., 2020). Following these findings, the prospective EVERRUN-registry was set up with a propensity-score analysis to compare clipping and ET. Functional outcomes, complication rates and final angiographic outcomes were all similar between both modalities, but there were more retreatments in the endovascular group (0% vs 12.7%) (Mascitelli et al., 2021).

Given the lower occlusion-rates of coiling and balloon-assisted coiling (BAC), **stent-assisted coiling** (SAC) was developed to provide an intravascular scaffold and achieve more durable endovascular results. A meta-analysis comparing SAC and non-SAC found that the use of a stent gave a higher complete occlusion rate (73.4% vs 61%) and fewer recurrences (4.8% vs 16.6%) (Zhang et al., 2019). The general complication-rate of SAC is estimated to be around 20.8%, with 9% experiencing thrombo-embolic complications (Bsat et al., 2020). Given the lack of prospective studies on this topic, the SAVE-registry was set up to evaluate SAC outcomes, but to date, a direct comparison between SAC and clipping is lacking (Li et al., 2022).

Flow diverters (FD) provide an alternative to SAC, as they provide additional flow modulation away from the aneurysm neck. Concerning ruptured saccular aneurysms, adequate occlusion was achieved in 79%, although this came at the cost of a 23% complication-rate, as thrombo-embolic and hemorrhagic complications occurred in 9.9% and 12% of patients. The complication rate for posterior circulation aneurysms was even higher at 27%. With these high complication-rates, many authors propose this technique only being used when no other endovascular and surgical options are available (Cagnazzo et al., 2018; Madaelil et al., 2017).

Both SAC and FD are examples of permanent intravascular devices, where (temporary) dual anti-platelet therapy (DAPT) is necessary to prevent thrombo-embolic complications and stent-occlusion. Ruptured aneurysms often require a ventriculostomy in case of hydrocephalus, and DAPT increases ventricular drain-related bleedings from 9% to 20.9% (Cagnazzo et al., 2020). Coronary-intervention studies also show that prolonged use of DAPT is associated with more major bleeding and non-cardiac deaths (Yin et al., 2019). Given these concerns, both SAC and FD remain second-choice options in daily practice when treating ruptured aneurysms.

To better deal with wide-neck aneurysms and obviate the need of DAPT, **intrasaccular flow disruptors** were developed. As these devices don't protrude into the parent vessel, anti-platelet therapy isn't always necessary. The Woven EndoBridge (WEB) has an adequate occlusion-rate of 84.8% in ruptured aneurysms. The complication-rate is lower than SAC and FD at 9.4%, and only 4.8% of cases needing retreatment. Most studies on WEB in ruptured aneurysms are based on retrospective data and showed no rebleeding (Monteiro et al., 2022). The only prospective data on rebleeding comes from the CLARYS-study, where no rebleeding was seen at one month in 60 patients (Spelle et al., 2021).

Wide-neck aneurysms seem to be the topic of discussion amongst ruptured aneurysms where both ET and clipping have their merits. Currently the best data comes from prospective studies comparing clipping and coiling/BAC. This data shows similar functional outcomes, complication rates, but again fewer retreatments in the clipped patients.

5.3. Location

Ruptured aneurysms in the anterior circulation are widely represented in ISAT (97.3% of aneurysms), apart from a relative underrepresentation of MCA aneurysms (comprising 14.1% of the population, compared to 20–30% in epidemiological studies) and distal anterior cerebral artery aneurysms (DACA). An overview is given on the management-decisions for the different locations of ruptured aneurysms in Table 2 (Etminan and Macdonald, 2021).

Table 2
Overview of aneurysmal locations influencing treatment outcomes for different modalities in ruptured IA. Abbreviations: RCT: randomized controlled trial, SR: systematic review, RS: retrospective study.

Ruptured aneurysms	Favors endovascular	No significant difference	Favors microsurgical	Most relevant study	Type of study
Posterior circulation	mRS			Molyneux et al., 2002	RCT
				Lindgren et al., 2018	SR
PICA	Fewer cranial nerve palsies	mRS	Occlusion	Ali et al., 2022	SR
OphA		mRS Mortality Occlusion		Falk Delgado et al., 2017	Meta-analysis
PComm	mRS			Taweesomboonyat et al., 2019	RCT
				Molyneux et al., 2005	RS
AComm		mRS Mortality Rebleeding	Occlusion Retreatment	Molyneux et al., 2005	RCT
				Moon et al., 2015	RCT
				Sattari et al., 2023	SR
DACA		mRS Morbidity	Occlusion Recurrence Rebleeding	Petr. et al., 2017	SR
MCA		mRS Occlusion		Zijlstra et al., 2016	SR

Posterior circulation aneurysms are generally being treated with ET, as surgery poses more difficulties with the deeper location of these aneurysms, important perforators and surrounding cranial nerves. Posterior circulation aneurysms were part of a subgroup-analysis in BRAT, which found better functional outcomes in the coiled group, with a good functional outcome at 1-year follow-up of 82% vs 36%, persisting at 3-years follow-up (75% vs 38%) (Spetzler et al., 2013). This point was further confirmed in a subgroup analysis of the Cochrane review of Lindgren et al., in 2018 (Lindgren et al., 2018).

Basilar apex aneurysms comprise the most frequently encountered posterior circulation aneurysms and follow every principle of a posterior circulation aneurysm.

Some debate remains among the **posterior inferior cerebellar artery** (**PICA**) aneurysms. These aneurysms are more superficially located, and the parent artery may have a tortuous course, sometimes necessitating more advanced ET. A systematic review with 17 studies on 455 saccular PICA aneurysms showed similar functional outcomes for clipping and ET, with better complete occlusion rates after clipping (95% vs 69%). When combining data from both ruptured and unruptured PICA aneurysms, a higher rate of cranial nerve palsies was observed after clipping (23% vs 2.4%). In-depth data concerning these cranial nerve palsies is lacking, as it isn't specified whether these are transient in nature or persistent (Ali et al., 2022).

> *In general, ruptured posterior circulation aneurysms are better treated through endovascular measures, some PICA aneurysms might be an exception where a surgical approach might be better suited when adjunctive endovascular measures other than simple coiling are necessary.*

Ophthalmic artery (OphA) aneurysms are quite rare, comprising around 5% of all intracranial aneurysms. The proximity of the optic nerve makes for a large morbidity risk after treatment. A meta-analysis on ruptured OphA aneurysms with 152 patients reported no differences in functional outcomes (76% and 71% after coiling and clipping respectively) and similar occlusion- and survival rates (Falk Delgado et al., 2017). To our knowledge, there are no comparative studies published on visual outcomes after treatment for a ruptured OphA.

PComm aneurysms were widely represented in ISAT (accounting for 25% of treated aneurysms), where a better functional outcome for endovascular therapy was seen one year after treatment (Molyneux et al., 2002). A single-center series with 189 PComm aneurysms with coiling and clipping showed similar functional outcomes for both groups, as well as similar complication rates (Taweesomboonyat et al., 2019).

Carotid artery aneurysms remain a poorly studied subject, where only a handful of studies exist on ruptured ICA aneurysms. The most convincing data comes from PComm aneurysms, where an endovascular approach was deemed favorable. Further studies on both PComm and OphA aneurysms fail to show any difference between both treatment modalities concerning functional outcomes.

AComm aneurysms represent the most frequent type of ruptured aneurysms (30–40%) and are often more complex aneurysms because of their double inflow and the presence of 2 or 3 outflow-branches (Fig. 2) (Perlmutter and Rhoton, 1976).

Subgroup analysis of AComm aneurysms in ISAT showed similar functional outcomes for both clipping and ET (Molyneux et al., 2005). A subgroup analysis of BRAT also found no differences in functional outcomes and retreatments (2.3%) at 1 and 3 years of follow-up between clipping and coiling (Moon et al., 2015). Further analysis of the BRAT-cohort and AComm aneurysms treated with ET in the post-BRAT era, was done to evaluate the influence of technological advancements such as BAC and SAC on patient outcomes. The updated cohort had significantly more WNA and showed similar functional outcomes and retreatment rates as before (Moon et al., 2017). A large systematic review with 18 studies and 2368 patients performed a subgroup analysis on ruptured AComm aneurysms, revealing similar functional outcomes (good mRS in 74.8% vs 60.3%), mortality rate (8.1% vs 11.9%) and rebleeding rates (1.7% vs 4.0%) between clipping and ET. Aneurysm obliteration was significantly higher in 89.1% in clipping (89.1%) versus ET (78.6%), with subsequent lower retreatment rates (4.4% vs 10.6%) and recurrences (3.1% vs 10.8%) (Sattari et al., 2023).

Some case series found anatomical factors, such as an aspect ratio of <1.6 and lower dome-neck ratios (Fig. 1), predictive of a surgical-approach as the preferred treatment option (Lee and Park, 2022; Darkwah Oppong et al., 2019). The orientation of AComm aneurysms is important in choosing a treatment approach, as anteriorly orientated aneurysms are more readily accessible with clipping, opposed to the posteriorly oriented aneurysms (Debono et al., 2004). With a posterior projection, more vessel occlusions and subsequent ischemia were seen after clipping, and it was pondered that these lesions should preferably be treated endovascularly, whereas the anterior-facing fundi were favored for surgery (Proust et al., 2003; Choi et al., 2011).

> *Current evidence on AComm aneurysms suggests similar outcomes for both patient groups concerning functional outcome, mortality and rebleeding rates. Aneurysm obliteration, retreatments and recurrences are all better for surgically treated patients. Specific anatomical factors such as aneurysm orientation should be considered, which can lead to a worse surgical outcome in posteriorly angulated aneurysms.*

Distal anterior cerebral artery aneurysms or pericallosal artery aneurysms have a small parent artery diameter, a wide neck or branching vessels originating from the aneurysm neck and are often associated with hematomas. Surgical caveats include the need for a parasagittal craniotomy with possible sacrifice of bridging veins (and associated venous infarction), as well as adherent cingulate gyri and a deep/narrow surgical corridor to reach these aneurysms. The endovascular treatment of these aneurysms is more challenging due to their distal location and the anatomical variations (Monroy-Sosa et al., 2017). As DACA aneurysms were only present in 4% of patients in ISAT, controversy concerning optimal treatment strategy still exists (Molyneux et al., 2002).

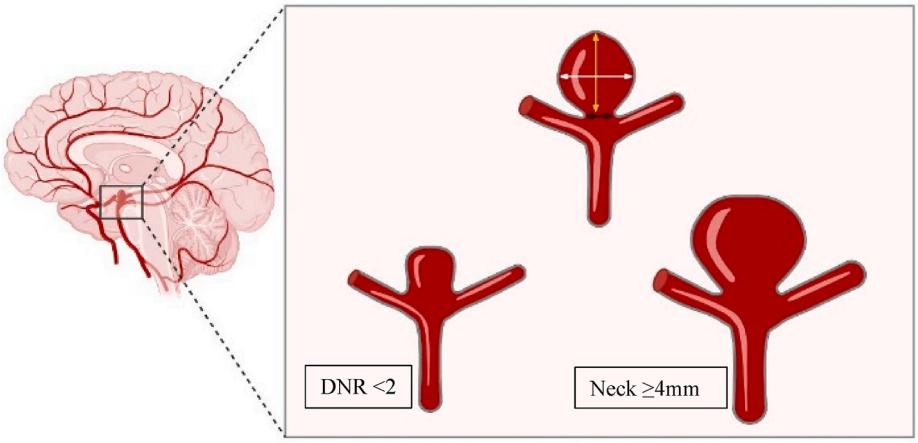

Fig. 1. Drawing representing 3 types of basilar apex bifurcation aneurysms. The top aneurysm represents a small-neck aneurysm, the black arrow measures the aneurysm neck, the white arrow measures the dome, and the yellow arrow measures aneurysm height. The dome-neck ratio (DNR) is calculated by dividing the dome- and neck diameters. The aspect ratio is the maximum height divided by the neck diameter. The two bottom aneurysms represent different types of wide-neck aneurysms. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

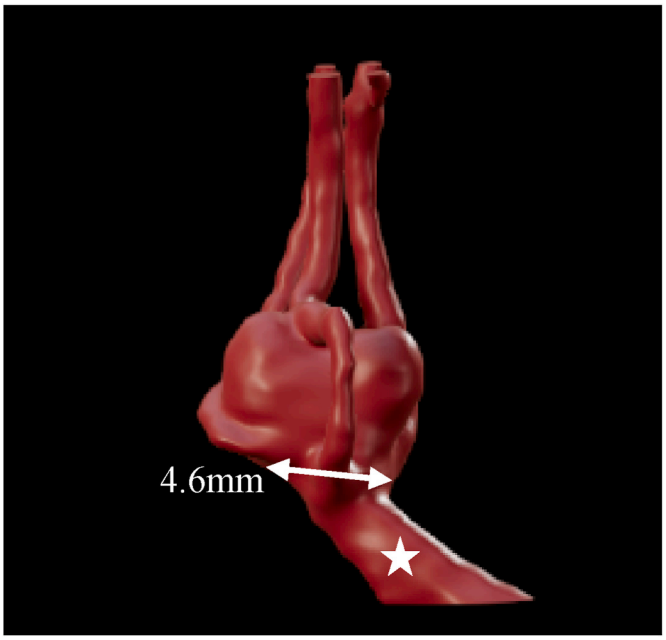

Fig. 2. Frontal view of a 3D-rendered wide-neck AComm aneurysm, originating from a solitary left anterior cerebral artery (*). The neck-width is measured at 4.6 mm, indicating a wide-neck aneurysm. Notice the trifurcational anatomy of the A2 branches, which surround the aneurysm dome.

Anatomical factors to guide treatment-decisions often rely on the relative position of the aneurysm compared to the genu of the corpus callosum. So-called supra-genu aneurysms are preferably treated surgically, and infra-genu aneurysms treated with ET for their ease of accessibility (Take et al., 2021; Carvi y Nievas, 2013). A systematic review with 30 studies and 1050 ruptured DACA aneurysms, found higher complete occlusion rates (94% vs 62%), less recurrences (3% vs 18%), rebleeding (2% vs 4%), and more technical completions (98% vs 90%) in the surgical group. There were no significant differences in functional outcomes, nor morbidity (16–19%) when comparing clipping and ET (Petr et al., 2017).

Based on these data, DACA aneurysms should preferably be treated by surgical means when the anatomy is favorable (supra-genu location). The infra-genu DACA aneurysms are more suitable for an endovascular treatment, given the similar functional outcomes.

Middle cerebral artery aneurysms are often treated surgically, due to their superficial location, wide necks and variable bi- or trifurcational anatomy, as well as vessels branching from the aneurysm dome. To date, there are no randomized trials which compare ET and clipping in patients with MCA aneurysms, but the MCAAT was initiated in 2021, a randomized study comparing both modalities in ruptured and unruptured MCA aneurysms (Darsaut et al., 2022).

Subgroup analysis of MCA aneurysms in the interim-analysis of the ISAT-2 trial did not find any differences in functional outcome but did reveal more adequate occlusions (91% vs 78%) at 1 year in favor of clipping (Darsaut et al., 2021). A subgroup analysis of clipped MCA aneurysms in the BRAT-cohort found a good functional outcome for HnH I-III patients in 70% and 36% in grade IV-V patients, and a complete obliteration in 88% of patients (Mooney et al., 2019). A systematic review with 51 studies and 4065 patients showed similar favorable clinical and angiographic outcomes when comparing coiling and clipping (Zijlstra et al., 2016).

It seems that in selected surgical series, microsurgical clipping has an advantage over coiling, but that disappears in a larger systematic review of observational studies. The results of the MCAAT, which will also randomize for ET and clipping in ruptured aneurysms, will provide a better insight in the preferred modality.

6. Conclusion

In this review, an overview is provided of the most relevant literature on decision-making for ruptured saccular intracranial aneurysms. As evident, only a handful of high-quality studies have been performed, and those who are still going on or recently finished, suffered from slow recruiting (ISAT-2). New randomized trials such as the MCAAT, are still being initiated, and should be encouraged, as to shed a better light on the current practice. Case series (prospective and retrospective) will always have inherent selection-biases which will influence the subsequent results and must be interpreted with caution. We aimed to select different systematic reviews when good RCT's were lacking, to give some idea where the current best available evidence lies. Very few guidelines exist to help in making a correct assessment for which treatment modality best suits a single aneurysm. As such, decision-making should always occur in a multi-disciplinary fashion with people directly involved with the patient. Not only neurosurgeons and

neuro-interventionalists should be present, but also neurologists, as to provide a neutral party in these discussions and outcome assessments.

The neurovascular community might feel the need to evolve towards more comprehensive, multimodal score systems that accurately capture the large diversity both of patients' and aneurysmal factors in decision-making steps for aneurysm repair in patients with aneurysmal subarachnoid hemorrhage.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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